CONTROL OF ARTIFICIAL HEARTS USING AUTONOMIC NERVOUS SIGNALS

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Abstract-**In order to develop an artificial heart system capable of being controlled by autonomic nervous signals, we have studied the methods of long-term stable recording of autonomic nervous signals and algorisms to utilize those signals to control an artificial heart system optimally. In this study, we have focused on the feasibility of the control of an artificial heart using the signals recorded from the cardiac sympathetic nerve and other nerves through animal experiments.**

INTRODUCTION

The development of a man-machine interface that can allow information to be sent by the human nervous system to control external equipment is extremely important for the development of the next generation of prosthetic devices, including artificial organs and limbs.

On the other hand, with regard to the control method of artificial heart systems, no definitive and reliable method has yet been developed, although several methods have been proposed and tested [1][2]. No methods have the necessary properties to respond to the variable demands of the living body. Our focus is on a method that uses neural information of the living body to control the artificial heart. With this method, we expect to achieve an artificial heart that can be controlled according to the demands of the natural circulatory center(Figure 1).

In order to realize neural prosthetic applications like this one, two essential problems are to be solved. They are:

1) how to establish a stable interface with the nervous system, and

2) how to translate the recorded nerve signals to control the artificial devices.

The first problem is the development of nerve electrodes. In terms of establishing an intimate and stable interfacing with the nervous system for a long term, the present technology of nerve electrodes is insufficient in many ways. In order to cope with this problem, the authors have been developing regeneration electrodes that have multi-channel recording and stimulating sites. The research is in the animal experimental stage [3].

Essentially, the target nerves where neural signals are measured are the cardiac nerves. However, it is difficult to measure the signals at this position because after implantation of the artificial heart, the cardiac nerves are too close to it and it is not possible to get a good S/N proportion. Therefore, we have also studied the use of signals recorded from the cervical autonomic nerve. To utilize the signal from this position, the signal should be properly analyzed.

The second problem is related to the analysis of the coding rule of nervous systems. To cope with this problem, it is necessary to investigate how control information is expressed in autonomic nervous systems.

As the preliminary step of this research, the authors have already reported an off-line experiment to control an artificial heart system using skin sympathetic nervous signals [4]. In this experiment, we used skin sympathetic nerve activity (SSNA) recorded by microneurography techniques as the parameter to determine the condition of an artificial heart system. We attempted to reproduce the change that takes place in the actual hemodynamics of the living body when nociceptive stimuli are given to a subject. To that end, we used a mock circulatory system connected with an artificial heart system and tried to control the driving condition of the artificial heart system by using sympathetic nervous activity information. This experiment demonstrated the possibility of controlling the driving

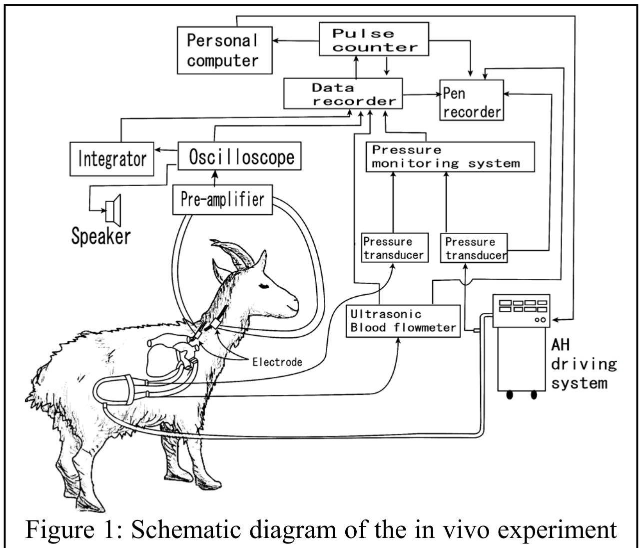

Figure 1: Schematic diagram of the in vivo experiment to control the driving condition of an artificial heart system using the information of the autonomic nervous system.

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Abstract

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conditions of an artificial heart system using sympathetic nervous activity. As the next step of our project, this paper describes the study that have focused on the feasibility of the control of an artificial heart using the signals recorded from the cardiac sympathetic nerve and other nerves through animal experiments.

GOALS

A) To investigate the feasibility of controlling an artificial heart system using cardiac sympathetic nerve activity and vagal nerve activity,

B) To study the correlation between cervical autonomic nerve activity and cardiac autonomic nerve activity. (If there is a good correlation between them, it can show that cervix autonomic nerve activity has enough properties to control artificial hearts), and

C) To investigate the design and desired properties of nerve electrodes to realize long-term stable recording.

METHODS

A Japanese white rabbit (weight, 2.5kg) was anesthetized by intravenous injection (4 ml/kg) of a mixture of urethan (250 mg/ml) and mechanically ventilated with oxygen-enriched air. Supplemental injections (1 ml/kg) were given when necessary to maintain an appropriate level of anesthesia. Aortic pressure was monitored using a catheter inserted into the femoral artery.

Through a midline thoracotomy, the left cardiac sympathetic nerve originating from the stellate ganglia, the vagal nerve, and the cervical autonomic nerves were identified. The nerve activity was recorded by a pair of hook-type stainless steel electrodes with an injection of Methoxamine hydrochloride or Nitroglycerin.

RESULTS

The activity of the cardiac sympathetic nerve shows apparent changes with negative correlation to the change of the aortic pressure. The latency between them was small enough to achieve quick control of an artificial heart that responds to the variable demands of the living body. The number of data was too small to reach a definitive conclusion about the correlation between cervical autonomic nerve activity and cardiac autonomic nerve activity. The mixture of the cardiac electrogram was diminished by the cut of the distal end of the cardiac sympathetic nerve.

DISCUSSIONS

[Goal A,B]

So far, the amount of data was too small for us to reach a definitive conclusion, but these results show the feasibility of the use of cardiac sympathetic nerve activity as the control signal of artificial hearts. We are conducting experiments to increase the amount of reliable data.

As the next step of our project, we are planning the off-line control of an artificial heart system using autonomic nerve signals.

[Goal C]

The target nerve was so close to the aortic arc that the vibration of the arc was easy to conduct. Therefore, when designing a chronic nerve electrode, the stability of the interface on the surface of the electrode as well as the mixture of the cardiac electrogram should be considered.

CONCLUSION

The feasibility of the control of an artificial heart using the signals recorded from the cardiac sympathetic nerve and other nerves was shown by an animal experiment.

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